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AXRO introduction and historical background

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Abstract. With the AXRO conference held in December 2017 in Prague, we celebrated the 10th anniversary of these international workshops on astronomical X–ray optics. In this contribution a short overview on the AXRO history and its background is given, including a short history of grazing incidence X–ray optics in the Czech republic.

Key words: X–ray optics – X-ray telescopes – X–ray astrophysics

1. Introduction

With the first X–ray lens produced around 1969/1970, astronomical X–ray optics has a long tradition in the Czech Republic. With this years AXRO (International Workshop on Astronomical X–ray Optics) conference in Prague (December 2017), we celebrated the 10th anniversary of these workshops. The goal of this contribution is to present and to briefly discuss the history of development of astronomical X–ray optics in the Czech Republic, and in addition to that, to present background and history of the international astronomical X-ray optics conferences AXRO. The Czech efforts in the field of astronomical X–ray optics in the past focused mainly on development and tests of numerous technologies, including novel techniques, novel materials, and novel designs.

2. History of Grazing Incidence X-Ray Optics in the Czech Republic

The AXRO history is related to the history of X–ray astronomy in general and to the history of X-ray optics developments in the Czech Republic (and formerly in Czechoslovakia) in particular.

The first Czech X-ray mirror was built already in the years 1969/1970, for a solar telescope within the Eastern Europe/Soviet INTERKOSMOS program (Hudec & Valníček, 1984). The early stages of the X-ray optics developments in the Czech Republic are closely related to the INTERKOSMOS Space Program (the Soviet and Eastern European equivalent to ESA, operated until 1989), see Fig.1. All of the X-ray imaging telescopes on board of soviet spacecrafts until 1990 were equipped with the Czech X-ray optics (exception: X-ray normal incidence mirrors in the special channel of the TEREK telescope). Later on, laboratory applications have been started in addition. A very short summary is given below.

- The total number of X-ray mirrors produced is more than 80.
- The total number of mirrors flown in space is 9.
- The total number of spacecrafts equipped with Czech X-ray optics is 5.
- The number of space experiments with Czech X-ray optics onboard is 9.

Figure 1. The early stages of the Czech X–ray optics developments. Left: Electroformed mandrel for musical records. Right: Replicated galvanoplastic Wolter 1 mirror with an aperture of 115 mm developed for the AUOS–S satellite. The mirror material was quite heavy, made from nickel with a wall thickness of around 1 cm

The first Czech X-ray mirror in space was the Wolter 1 mirror (50 mm aperture) on the Vertikal 8 rocket (Hudec et al., 1984), as illustrated by Fig. 2. In this historical experiment, soft X-ray images of the sun were obtained in an experimental trial of the f/45 RTF imaging telescope (using a 6 micron-thick Al filter for 0.8 -2.2 nm wavelengths and a 20 micron thick Be filter for 0.6 - 2.0 nm) during the Vertikal-8 high-altitude rocket flight of September 26, 1979, with the data being analyzed using digital processing techniques. The two images are found to be underexposed, so that only one active region, corresponding in position to McMath 16298, could be defined. The method of filter ratios was used to calculate the temperature and emission measure of the region as $(1.3 \pm 0.5) \cdot 10^6$ K and $4 \cdot 10^{29}$ cm^{-3}, respectively. This experiment was repeated in 1980 with Vertikal 11 rocket flight. There were always two X–ray telescopes on board (both with our 50 mm aperture X–ray Wolter mirror), one in collaboration with CBK Wroclaw, Poland, and the second one in collaboration with FIAN Lebedew Institute in the Soviet Union.

The most recent Czech X–ray mirror in space is then the 1D LE module on the VZLUSAT–1 cube satellite (Pína et al., 2016; Urban et al., 2017a). Further experiments are planned in the near future, for example the sounding Water Recovery X-ray Rocket (Dániel et al., 2017; Stehlikova et al., 2017a) with iridium coated X-ray mirrors (Stehlikova et al., 2017b).

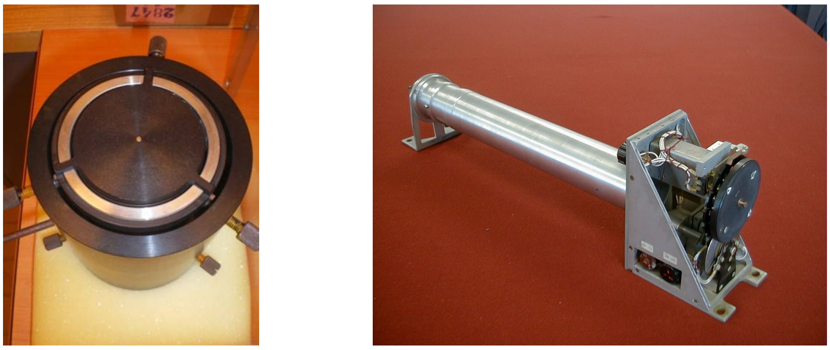

Figure 2. First space experiment with Czech grazing incidence X–ray optics was the X–ray telescope with photographic recording developed in collaboration with Poland and Soviet Union for the Vertikal 8 rocket flight in 1979. Left: The X–ray mirror. Right: The telescope.

And a very concise history of Czech astronomical X–ray mirrors follows here.

- 1969 first considerations started
- 1970 first solar X-ray mirror produced (Wolter 1, aperture 50 mm)
- 1971 Wolter 1 (aperture 80 mm)
- 1976 Wolter 1 (aperture 115 mm)
- 1979 first mirrors flown in space (two Wolter 50 mm in 2 experiments, Vertikal 9 rocket)
- 1980 Vertikal 11 rocket (two Wolter 50 mm in 2 experiments)
- 1981 first large Wolter mirror (aperture 240 mm)
- 1981 Salyut 7 orbital station (RT–4M X–ray telescope, Wolter 240 mm nested)
- 1985 applications for plasma physics, EH 17 mm, PP 20 mm
- 1987 first high quality X-ray foils for foil mirror X-ray telescope (SODART)

– 1988 Fobos 1 Mars probe, TEREK X-Ray Telescope, 80 mm Wolter 1
– 1989 KORONAS I X-ray mirror, Wolter 80 mm
– 1990 first micromirror (aperture less than 1 mm)
– 1993 collaboration with SAO, USA on a WF X-ray optics started
– 1996 first Lobster Eye (LE) test module, produced in Schmidt geometry
– 1997 double-sided X-ray reflecting flats
– 1997 Lobster Eye Angel geometry project started
– 1999 first Lobster Eye test module produced (Angel geometry)
– 2001 thin segmented X-ray mirrors
– 2004 thermal glass forming of samples of laboratory X-ray optics started
– 2005 replication of multilayers for X-ray optics
– 2006 X-ray optics based on Si wafers, Si wafers shaping started
– 2009 K-B (Kirkpatrick–Baez) Optics started
– 2014 1D LE optics
– 2015–2017 various LE and KB modules, AHEAD KB module, VZLUSAT–1 1D LE, REX LE.

The from gramophone industry adopted replication technology (Hudec et al., 1981) (Fig. 1), used for most of the Wolter mirrors developed between 1970 and 1990, was modified and upgraded several times with emphasis of internal stress reduction so that at later stages several copies from one polished mandrel were possible to be produced without mandrel degradation (Hudec & Valníček, 1984; Hudec et al., 1988), as documented by Fig. 3 and Fig. 4.

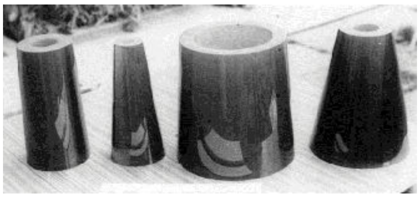
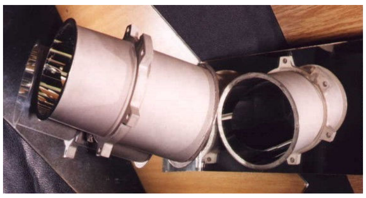

Figure 3. Galvanoplastic X–ray astronomical mirrors. Left: The four glass ceramics mandrels used for the Salyut 7 orbital station RT–4M X–ray telecope (with double nested Wolter 1 mirror with aperture of 240 mm, outer shell with Ni surface, inner shell with Au reflecting layer deposited by electroforming). Right: The two identical Wolter mirrors with 80 mm aperture for he KORONAS satellite.

Figure 4. The X–ray optics laboratory at the Ondrejov Observatory of the Astronomical Institute of the Czech Academy of Sciences, demonstrating the various technology tests.

It should be noted that the development before 1987 was done completely independent, without any contact to other groups abroad and without access to relevant literature and/or meetings and workshops. The development of galvanoplastic replication was also completely independent on efforts abroad.

The work was focused mainly on various technology developments and tests with verification on small mirrors, see Fig. 5.

The Czech X–ray optics consortium included many Czech Institutes and subjects over these past years, e.g. ASU AV CR, VUGT Lodenice, SVUM Prague, CTU in Prague, Institute of Chemical Technology in Prague, Optical workshop in Turnov, Reflex s.r.o., Rigaku RITE Prague, ON Semiconductor, and others.

There were also essential efforts devoted to the development of novel technologies for satellite projects which were either cancelled or interrupted. The two wasted years of development on the technology of high quality Ni foils for the Danish SODART telescope (Schnopper, 1990), 1986-1988, can serve as an example. The SOviet-DAnish Roentgen Telescope (SODART) was planned for on board the Spectrum Roentgen Gamma (SRG) satellite equipped with three different instruments devoted to X–ray spectroscopy. Each of the two thin foil telescopes had an 8 m focal length, a 60 cm diameter, a 1 deg field-of-view (FOV), a half-power width better than 2 arcmin and ca. 1 700 and 1 200 cm^2 collecting area at 2 and 8 keV, respectively.

Figure 5. Visit of the US Astronaut with Czech family origin John Blaha in the X–ray optics laboratory at the Ondrejov Observatory in 1998. From the left to the right: Rene Hudec, Astronaut John Blaha and his wife.

For this project, we have developed and tested galvanoplastic replication of glass flat mandrels, sizes up to 300 × 400 mm, and were able to demonstrate that the thickness homogeneity of replicated flat nickel foils during the project improved from 8 % to 2 %.

The galvanoplastic replication (or electroforming technology according to the term used by other teams) technology was originally adopted from gramophone industry namely under collaboration with large gramophone company located in Lodenice near Prague.

3. X–ray optics on VZLUSAT–1

The VZLUSAT–1 cubesatellite is the most recent satellite with Czech X–ray optics onboard. It represents an example of 2U cubesatellites with advanced astrophysical payload onboard (Dániel et al., 2016; Urban et al., 2017a). One of the payloads is represented by an one dimensional (Pína et al., 2016) miniature X–ray telescope (Pina et al., 2015) with a Timepix detector (Llopart et al., 2007; Urban et al., 2017b) in its focal plane (Baca et al., 2016). The main mission goal is the technological verification of the system, but scientific outcome is also expected for some bright celestial X–ray sources (Blazek et al., 2017; Daniel et al., 2016). This satellite represents the 5th satellite with Czech X–ray optics onboard.

4. History of AXRO workshops

The history of AXRO workshops is dated back to May 2007, when the Czech-US Seminar on Astronomical X-Ray Optics was organized in Prague, with participation of six leading US specialists in the field of astronomical X-ray optics. This seminar was attended by many Czech scientists and it was very productive,

Figure 6. The participants of the first US–Czech seminar on astronomical X–ray optics, Prague, May 2007, with a remarkable train trip to ON Semiconductor company in Roznov pod Radhostem, where the participants were able to see the production of high–quality silicon wafers recently used in various X–ray optics applications.

Figure 7. Participants of the 1st AXRO workshop held in Prague, December 2008.

as documented by Fig. 6. At the workshop, we have decided to repeat it with opening it to the international astronomical X–ray optics community. The first AXRO workshop was then indeed organized in Prague, at the historical Vila Lanna, in December 2009, see figure 7, and since then the astronomical X–ray optics scientists meet there every year in the second week in December.

5. Conclusion

The development of astronomical X–ray optics has a long tradition in the Czech republic with emphasis on development and tests of innovative approaches and technologies. Since 2007 we also organize a very successful and productive series of international workshops with ample time for discussions among participants.

The Czech X–ray optics consortium included many Czech Institutes and subjects over these past years, e.g. ASU AV CR, VUGT Lodenice, SVUM Prague, CTU in Prague, Institute of Chemical Technology in Prague, Optical workshop in Turnov, Reflex sro, Rigaku RITE Prague, ON Semiconductor, and others.

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